SEISMIC HAZARD ZONE REPORT FOR THE VENTURA 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

2002

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California Geological Survey

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SEISMIC HAZARD ZONE REPORT 067

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Ventura 7.5-minute Quadrangle, Ventura County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 45 square miles at a scale of 1 inch = 2,000 feet.

The Ventura Quadrangle covers about 45 square miles of land along the Pacific Ocean coastline in southwestern Ventura County. Most of the quadrangle is mountainous terrain dissected by numerous canyons. Lowlands in the quadrangle lie along the Ventura River and beneath the City of Ventura in the southeastern corner. The Ventura River and its eastern tributary in Canada Larga comprise the major drainage. Additional drainage courses include Coyote Creek (blocked by the dam that impounds Lake Casitas) and the creeks draining, Aliso, Del Diablo, Rodriguez, and De San Joaquin plus Fresno, Weldon, and Miguel canyons. Elevations range from sea level to 2163 feet along the ridgeline of Red Mountain that lies between the Lake Casitas basin and the ocean. The quadrangle includes part of the City of San Buenaventura and the unincorporated community of Casitas Springs near the northern boundary. U.S. Highway 101 and State Highway 33 are the major routes through the quadrangle. Most of the mountainous land within the quadrangle is undeveloped except for intensive oil field facilities along the axis of the Ventura Avenue Anticline. Residential and commercial development fills most of the coastal plain and the lowlands along the Ventura River.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years.

In the Ventura Quadrangle the liquefaction zone covers the urbanized lowlands occupied by the City of Ventura, the Ventura River floodplain, the beaches, and the bottoms of some creek canyons. The combination of deeply dissected hills and weak rocks has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 63 percent (about 27 square miles) of the land portion of the Ventura Quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://gmw.consrv.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Ventura 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Ventura 7.5-Minute Quadrangle, Ventura County, California

By
Ralph C. Loyd

California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Ventura 7.5-minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, including areas in the Ventura Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Ventura Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The land portion of the Ventura 7.5-minute Quadrangle, which borders the Pacific Ocean, covers approximately 45 square miles in southwestern Ventura County. Local physiography is dominated by the rugged slopes of the Transverse Ranges, which occupy all but about 8 square miles of land within the quadrangle. The Ventura River is the major drainage in the quadrangle. Its tributaries include Coyote Creek (blocked by the dam that impounds Lake Casitas) and the creeks draining Canada Larga, Aliso, Del Diablo, Rodriguez, and De San Joaquin plus Fresno, Weldon, and Miguel canyons. Incised creeks including Prince Barranca (from Hall Canyon) and Sanjon Barranca dissect the hills north of the city of Ventura. Elevations range from sea level to 2,163 feet along the ridgeline of Red Mountain that lies between the Lake Casitas basin and the ocean. The quadrangle includes part of the City of San Buenaventura (commonly referred to as the City of

Ventura, which is the county seat) and the unincorporated community of Casitas Springs in the Ventura River floodplain. U.S. Highway 101 and State Highway 33 are the major routes through the quadrangle. Most of the mountainous land within the quadrangle is undeveloped except for the very large Ventura Oil Field along the axis of the Ventura Avenue Anticline. Residential and commercial development fills most of the coastal plain and the lowlands along the Ventura River where either the County of Ventura or the City of Ventura administers land use.

GEOLOGY

Bedrock and Surficial Geology

Geologic units generally susceptible to liquefaction in the Ventura Quadrangle include late Quaternary alluvial and fluvial sedimentary deposits, beach deposits, and artificial fill. William Lettis and Associates (WLA) (2000) provided a digital Quaternary geologic map of the Ventura Quadrangle (Plate 1.1). To provide a common geologic map for use in zoning both liquefaction and earthquake-induced landslides this map was merged with a digitized version of the bedrock geologic map by Dibblee (1988). Nomenclature for labeling Quaternary geologic units followed that applied by the Southern California Area Mapping Project (Morton and Kennedy, 1989). The distribution of Quaternary deposits on this map was used in combination with other data, discussed below, to evaluate liquefaction potential and develop the Seismic Hazard Zone Map. Geologic mapping by Staal, Gardner, and Dunne, Inc. (1992) was also considered during this investigation

Young Quaternary deposits (Plate1.1) cover about 13 percent of the Ventura Quadrangle. William Lettis and Associates (2000) mapped the various geologic units primarily on the basis of depositional environment, geomorphic expression, and relative ages, as largely determined by topographic position, degree of soil profile development, and degree of surface erosion. Most of the exposed valley alluvium is Holocene, with older Quaternary sediments locally exposed on the lower slopes of the surrounding hills. Most Holocene sediments exposed along the Ventura River valley are wash (Qw), alluvial (Qya), or alluvial fan (Qyf) deposits. Those Holocene sediments exposed in the lowland area in the southeastern corner of the quadrangle are mainly alluvial fan (Qyf) and marine (Qym) deposits. Surficially, the alluvial fan units are composed of material that ranges in size from boulders to clay, with silt and clay being the major components.

Principal bedrock units exposed in the Ventura Quadrangle consist of sandstone of the Pleistocene Saugus Formation, sandy beds of the early Pleistocene Las Posas Formation, claystone of the Pliocene Pico Formation, and sandstone beds of the Oligocene Sespe Formation (Dibblee, 1988). It is important to note the general lithologic composition of the various Quaternary units deposited in the lowland areas of the Ventura Quadrangle is governed, in large part, by the distribution of bedrock units in the adjacent highland regions. For example, if a basin is situated adjacent to highlands where exposed bedrock units are primarily claystone, then alluvial deposits filling that basin will contain abundant clay. Conversely, if sandstone is exposed over much of the drainage area, alluvial deposits will contain abundant sand. However, if various types of rocks are exposed in the drainage area, alluvial deposits tend to alternate between fine- and coarser-grained materials depending on fluctuations in stream energy, changes in active stream channels, and variations of erosion rates within the drainage basin due to localized landsliding, fires, and other natural processes. Conditions governing deposition of alluvial fans in the Ventura Quadrangle, which contain sediment layers ranging from clay to boulders, appear to be related closely to variations in erosion rates. Refer to the earthquake- induced landslide portion (Section 2) of this report for further details on the bedrock units exposed in the Ventura Quadrangle.

CGS conducted a subsurface investigation of Quaternary sedimentary deposits in the Ventura Quadrangle using geotechnical borehole logs collected from the files of the Ventura County Water Resources and Engineering Department, Ventura County Hazardous Substances Control Program, and the California Department of Transportation (CalTrans). Locations of the exploratory boreholes considered in this investigation are shown on Plate 1.2. Staff entered the data from the geotechnical logs into CGS's GIS in order to create a database that would allow effective examination of subsurface geology through construction of computer-generated cross sections and evaluation of liquefaction potential of sedimentary deposits through the performance of computer-based quantitative analysis (see Engineering Geology section).

Construction of cross sections using data entered into the GIS database enabled staff to examine the nature and distribution of various depositional units in the subsurface, to correlate soil types from one borehole to another, extrapolate geotechnical data into outlying areas containing similar soils, and evaluate historic groundwater depths. Cross-sections generated in the Ventura Quadrangle show distinct lithologic signatures in the various geologic environments present. For example, the alluvial fans developed along the base of the hills north of Main Street and Foothill Road in San Buenaventura are composed of alternating and mixed beds of gravel, sand, silt, and clay, with sand being the most abundant constituent. On the other hand, in the subsurface beds deposited within the floodplain of the Ventura River are composed predominantly sand and silt rich in cobble and boulder clasts, although occasional beds of clay are present.

Structural Geology

The Ventura Quadrangle lies within the Transverse Ranges geomorphic province, which is characterized by west-trending folds, thrust faults, and fault-bounded valleys. The structural framework of the region is generally considered the result of regional compression caused by right-lateral, strike-slip movement on the "Big Bend" segment of the San Andreas Fault. Folded and faulted Oligocene to lower Pleistocene sedimentary rocks distinguish the structure of the Ventura Quadrangle. Major faults in the region are west trending reverse faults. One of these is the Ventura Fault whose 7-mile long inferred trace extends along the base of the hills generally following Poli Street and Foothill Road and continuing east into the adjacent Saticoy Quadrangle (Dibblee, 1988, 1992). This fault is identified as an Official Earthquake Fault Zone by CGS (DOC, 1978).

In addition, the inferred trace of the west-trending Oak Ridge Fault is mapped less than a mile north of the Ventura Quadrangle boundary. Although this fault currently does not meet the criteria required for inclusion in an Official Earthquake Fault Zone (it is not a well-defined fault), it is considered to be an active seismic source (Cramer and Petersen, 1996; Petersen and others, 1996). Rupture along either of these local faults, or shaking produced by large to great earthquakes in the general region, could trigger liquefaction, locally, within alluviated areas of the Ventura Quadrangle.

ENGINEERING GEOLOGY

In addition to the borehole log data mentioned above, 46 of 76 borehole logs collected during this study of the Ventura Quadrangle record Standard Penetration Test (SPT) results or normalized SPT results that provide information on the density, or compactness, of Quaternary sedimentary layers penetrated by a borehole. This test, along with the results of other engineering tests (dry density, moisture content, sieve analysis, etc.) are used in the Seed-Idriss Simplified Procedure (Seed and Idriss (1971) to evaluate liquefaction potential of a site (see Part II of this section - Quantitative Liquefaction Analysis). The SPT involves recording the number of blows required to drive a 1.4-inch inside diameter split-spoon sampler one foot into the soil using a 140-pound hammer-weight dropped 30 inches. The test is conducted in compliance with American Society for Testing and Materials (ASTM) D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ within accepted limits, are converted to SPT-equivalent blow count values and entered into the CGS GIS. It must be noted that the reliability of the SPT-equivalent values varies. Therefore, they are weighted and some are used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials. The actual and converted SPT blow counts are normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

It is important to note that the Seed-Idriss Simplified Procedure was developed primarily for clean sand and silty sand and results depend greatly on accurate measurement of in-situ soil density. However, the cross sections generated in this study show that some of the young Quaternary alluvial deposits contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations are made with boreholes in the same unit where the N (blow count) values do not appear to be affected by gravel content.

In the Ventura Quadrangle, boreholes whose logs were collected during this project penetrated more than 3650 linear feet of Quaternary sediments. The percentages of major soil types and statistical information regarding the number and results of penetration tests performed in each soil type are summarized in Table 1.1. Clearly, loose sandy and silty soils dominate the Holocene stratigraphic section in alluviated lowland areas of the quadrangle. SPT and SPT-normalized blow-count values indicate that the majority of sandy and silty layers deposited in the upper 40 feet of alluvial units, regardless of environment or relative Holocene age of deposition (Qyf1, Qyf2, Qya, and Qw), are composed of loose (5-15 blows) to moderately dense (25-30 blows) material (Table 1.1 and Figure 1.1). Sample intervals having high blow counts (>60 blows) commonly reflect gravel, cobble, or boulder clasts in a matrix of sand, silt, or clay as indicated in the lithologic descriptions in the logs. The penetration test results indicate that the uppermost 40 feet of valley alluvium deposits throughout the Ventura Quadrangle are composed of younger Quaternary material. Dry density values and lithologic notations support this conclusion. Therefore, liquefaction potential of sediments in the Ventura Quadrangle is principally governed by depth to ground water and the clay-silt-sand proportions of deposits lying within 40 feet of the surface.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. CGS uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the Ventura Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from the Ventura County Water Resources and Engineering Department, United Water Conservation District, California Department of Transportation, and California Department of Water Resources. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Most of the alluviated lowland areas within the Ventura Quadrangle are characterized by historical ground-water levels of less than 40 feet (Plate 1.2). Exceptions are the higher-elevation portions of alluvial fans developed along the eastern side of the Ventura River Valley. Ground-water levels in canyon areas of the quadrangle are assumed to be generally shallow, about 10-foot depth. Such conditions commonly exist in this type of depositional environment because the canyon bottoms tend to receive and accumulate heavy runoff and near-surface ground water derived from surrounding highlands during wet seasons.

Lithology	% of Total Sediment Drilled/Logged	Number of Penetration Test Samples *	Blow Count Range (<60 Blows)	Blow Count Mean	Blow Count Median	Coefficient of Variation
CL, CH, MH, AF	17	42/45	2 – 42	10.9	9	0.82
ML	26	55/64	4 – 54	17.2	14	0.75
SC	3	10/12	7 – 34	16.1	16	0.52
SM	21	37/46	3 – 60	19.0	17	0.62
SW	9	20/27	5 – 60	28.7	26	0.62
SP	14	35/53	3 – 51	19.9	19	0.60
GC, GM, GW,GP	10	7/30	10 – 60	38.0	35	0.31

* Number of penetration tests with SPT or SPT equivalent blow counts ($N_{1(60)}$) less than 30 / total number of penetration tests performed. Soils with blow counts greater than 30 are considered too dense to liquefy.

Table 1.1. Summary of Lithologic Composition of 3,650 Linear Feet of Boreholes Logged in the Ventura Quadrangle along with Statistical Results of Penetration Tests Performed.

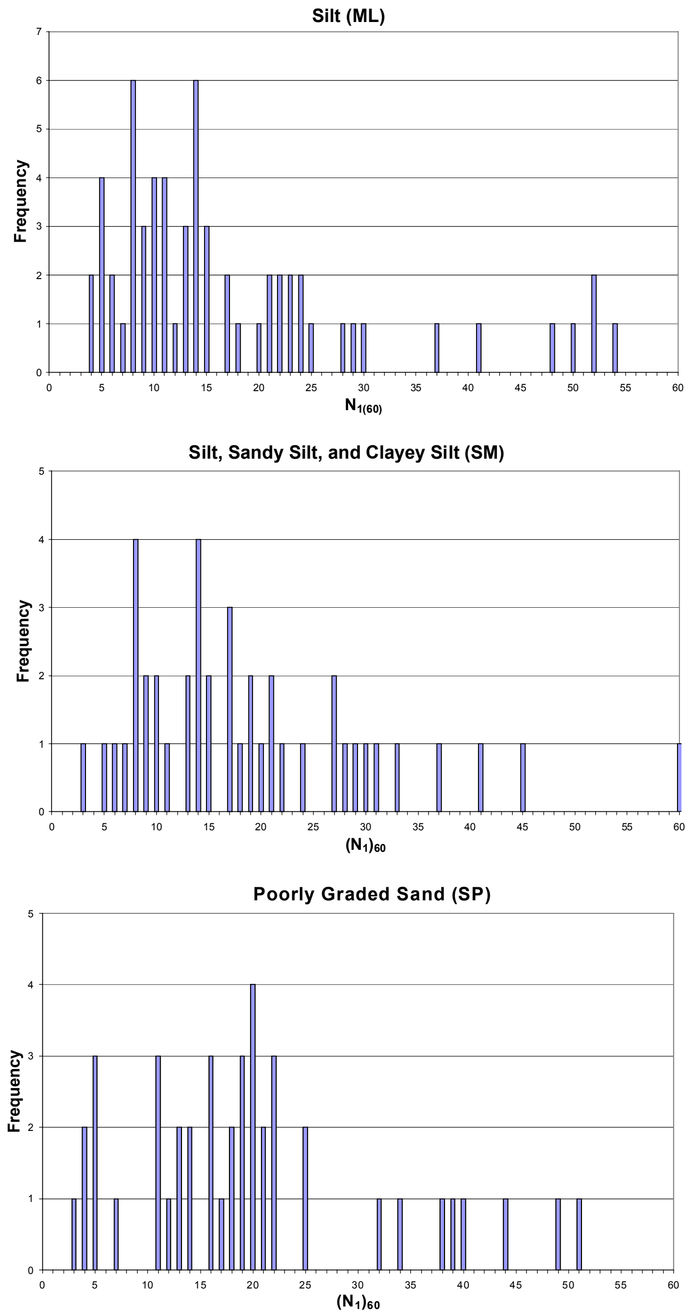

Figure 1.1. Distribution of Penetration Test Results $(N_1)_{60}$ from Silt, Silty Sand, and Poorly Graded Sand Deposits in the Ventura Quadrangle. Not shown are the few tests performed in clayey sand and well-graded sand (statistically invalid).

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations between general liquefaction susceptibility and geologic map units are summarized in Table 1.2.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qw, Qw2, Qw1	Gravel, sand, silt	Stream channels	Loose	Yes
Qf	Sand, silt, clay	Active alluvial fans	Loose	Yes**
Qyf1-2 , Qya1-2	Sand, silt, clay	Young alluvial fan and valley deposits	Loose to moderately dense	Yes**
Qoa, Qof	Clay, silt, sand, and gravel deposits.	Older alluvial deposits	Dense to very dense	Not likely

* When saturated. ** Not likely if all clay or sand and silt layers are clayey.

Table 1. 2. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Ventura Quadrangle, PGAs of 0.60g to 0.65g resulting from earthquakes of magnitudes of 6.8 to 6.9 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Ventura Quadrangle is summarized below.

Areas of Past Liquefaction

Examples of historical liquefaction have not been found for the Ventura Quadrangle nor have areas showing evidence of paleoseismic liquefaction been reported. However, excerpts from an 1858 topographic survey report that describe ground lurch cracks in the bed of the Santa Clara River somewhere in the vicinity of San Buenaventura immediately after the 1857 Fort Tejon earthquake are referred to in a seismic hazards report by the California Division of Mines and Geology (1976).

Artificial Fills

In the Ventura Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

In general, sufficient geotechnical data to adequately evaluate potential for liquefaction exists over most of the alluviated valley areas of the Ventura Quadrangle. Borehole log data clearly demonstrate that young Quaternary stream wash (Qw) and valley alluvium (Qya) deposits in the Ventura River stream valley are composed predominantly of loose sandy soils that are saturated within the upper 40 feet of the surface. In addition, borehole logs show that the upper parts of the alluvial fans developed along the base of the Ventura Hills between the Ventura River and Arundell Barranca contain saturated loose sand and silt.

Areas with Insufficient Existing Geotechnical Data

SMGB criteria for zoning areas with insufficient existing geotechnical data is applied to alluvial fan deposits in the southeast corner of the quadrangle, east of Harbor Blvd and generally south of Thompson Street. Borehole log data in adjacent areas indicate that sedimentary layers forming these more distal alluvial fan deposits are generally finer grain, with clay and clayey silt becoming the dominant soil type. However, lack of borehole log data in the immediate area cannot rule out the presence of potentially liquefiable sand and silt layers in the upper 40 feet of the section. Therefore, this area is included within the zone of required investigation.

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REFERENCES

American Society for Testing and Materials, 1999, Standard test method for penetration test and split-barrel sampling of soils, Test Method D1586-99, *in* Annual Book of ASTM Standards, v. 4.08.

Budiman, J.S. and Mohammadi, Jamshid, 1995, Effect of large inclusions on liquefaction of sands, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 48-63.

California Department of Conservation, Division of Mines and Geology, 1978, Official Map of Earthquake Fault Zones, Ventura Quadrangle, scale 1:24,000.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones in California, Special Publication 118, 12 p.

California Division of Mines and Geology, 1976, Seismic hazards study of Ventura County, California: Open File Report 76-5 LA, 396 p., map scale 1:48000.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Dibblee, T.W., Jr., 1988, Geologic map of the Ventura and Pitas Point quadrangles, Ventura County, California: Dibblee Geological Foundation Map DF-21, scale 1:24000.

Dibblee, T.W., Jr., 1992, Geologic map of the Saticoy Quadrangle, Ventura County, California: Dibblee Geological Foundation Map DF-42, scale 1:24000.

Evans, M.D. and Zhou, Shengping, 1995, Liquefaction behaviour of sand-gravel composites: American Society of Civil Engineers, Journal of Geotechnical Engineering, v. 121, no. 3, p. 287-298.

Harder, L.F. and Seed, H.B., 1986, Determination of penetration resistance for coarse-grained soils using the Becker hammer drill: University of California at Berkeley, College of Engineering, Earthquake Engineering Research Center, report no. UCB/EERC-86/06, 126 p.

Ishihara, Kenji, 1985, Stability of natural deposits during earthquakes, *in* Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, San Francisco, v. 1, p. 321-376.

Morton, D.M. and Kennedy, M.P., 1989, A southern California digital 1:100,000-scale geologic map series: The Santa Ana Quadrangle, The first release: Geological Society of America Abstracts with Programs v. 21, no. 6, p. A107-A108.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, Tianqing, Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.

Seed, H.B. and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.

Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, H.B., Tokimatsu, Kohji, Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Earthquake Center, 1999, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating liquefaction in California: Southern California Earthquake Center, University of Southern California, 63 p.

Staal, Gardner, & Dunne, Inc., 1992, Reconnaissance geohazards study and grading ordinance review, City of San Buenaventura, Ventura County, California; Consulting report prepared for the City of San Buenaventura, 40 p., 21 plates, map scale 1:24000.

Sy, Alex, Campanella, R.G. and Stewart, R.A., 1995, BPT-SPT correlations for evaluations of liquefaction resistance in gravelly soils, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic Properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 1-19.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region — An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316.

William Lettis and Associates, 2000, Digital Quaternary geologic map of the Ventura 7.5-minute Quadrangle: digitized at scale 1:24000.

Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Ventura 7.5-Minute Quadrangle, Ventura County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Ventura 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Ventura Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink, 2001; McCrink and Real, 1996) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Ventura Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Ventura Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The land portion of the Ventura 7.5-minute Quadrangle, which borders the Pacific Ocean, covers approximately 45 square miles in southwestern Ventura County. Local physiography is dominated by the rugged slopes of the Transverse Ranges, which occupy all but about 8 square miles of land within the quadrangle. The Ventura River is the major drainage in the quadrangle. Its tributaries include Coyote Creek (blocked by the dam that impounds Lake Casitas) and the creeks draining Canada Larga, Aliso, Del Diablo, Rodriguez, and De San Joaquin plus Fresno, Weldon, and Miguel canyons. Incised creeks including Prince Barranca (from Hall Canyon) and Sanjon Barranca dissect the hills north of the city of Ventura. Elevations range from sea level to 2,163 feet along the ridgeline of Red Mountain that lies between the Lake Casitas basin and the ocean. The quadrangle includes part of the City of San Buenaventura (commonly referred to as the City of Ventura, which is the county seat) and the unincorporated community of Casitas Springs in the Ventura River floodplain. U.S. Highway 101 and State Highway (Ojai Freeway) 33 are the major routes through the quadrangle. Most of the mountainous land within the quadrangle is undeveloped except for the very large Ventura Oil Field along the axis of the Ventura Avenue Anticline. Residential and commercial development fills most of the coastal plain and the lowlands along the Ventura River where either the County of Ventura or the City of Ventura administers land use. The northern part of the quadrangle is primarily used as ranchland

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map. Within the Ventura Quadrangle, a Level 2 Digital Elevation Model (DEM) was obtained from the U.S. Geological Survey (USGS, 1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1947 in the hilly portions of the quadrangle were updated to reflect the new topography. A DEM reflecting this recent grading was obtained from an airborne interferometric radar platform flown in 1998, with an estimated vertical accuracy of approximately 1.5 meters (Intermap Corporation, 2002). An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. The DEM used for the graded areas within the Ventura Quadrangle underwent additional processing to remove these types of artifacts (Wang and others, 2001). Nevertheless, the final hazard zone map was checked for potential errors resulting from the use of the radar DEM and corrected if necessary. Graded areas where the radar DEM was applied are shown on Plate 2.1

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The bedrock geologic map used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee, 1988) and digitized by CGS staff for this study. A map of the Quaternary (surficial) geology was obtained in digital form from William Lettis and Associates (2000). Bedrock units exposed in the Ventura Quadrangle are described in detail in this section. Surficial geologic units are discussed in more detail in Section 1.

CGS geologists modified the digital geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory created during this study would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were also revised based upon comparisons between the two source maps. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to the development and abundance of slope failures was noted.

Bedrock units of the Ventura Quadrangle range in age from Oligocene to Pleistocene. Quaternary surficial deposits are limited to areas along active river and stream channels, elevated terraces, alluvial and fan gravels, shallow landslides and debris flows, and beach areas. Engineered fills are mostly located along roadways and other man-made structures, including the marina in the southeastern quadrant.

The oldest geologic unit exposed in the Ventura Quadrangle is the predominantly Oligocene non-marine Sespe Formation (Tsp). The Sespe Formation occupies most of the northwestern quadrant of the Ventura Quadrangle (Dibblee, 1988). Within this area of Sespe Formation is Red Mountain, which derives its name from the reddish-stained strata formation (Bailey, 1947). Sespe Formation formed in a non-marine depositional environment, and consists mostly of pinkish-gray to light brown, moderately hard, arkosic sandstone, which is locally pebbly, with interbedded maroon to red siltstone and claystone. The red claystone is most abundant near the top of the sequence. Sespe Formation rocks exposed within the Ventura Quadrangle have been folded and faulted and represent a rugged area of resistant beds surrounded by weaker, younger sedimentary units. Most notable is the sinuous ridge formed by the axis of the Red Mountain Anticline.

Early Miocene, shallow marine transgressive, Vaqueros Sandstone (Tvq) conformably overlies the Sespe Formation in the Ventura Quadrangle. Vaqueros Sandstone crops out as shallow to steeply dipping beds, which surround the deformed Sespe Formation beds of the

Red Mountain Anticline. Vaqueros Sandstone consists of massive to poorly bedded, light gray to tan, fine-grained sandstone and conglomerate, which is locally calcareous.

Early Miocene marine Rincon Shale (Tr) is conformable on the Vaqueros Sandstone and consists of poorly bedded, gray clay shale and siltstone, with occasional gray dolomitic concretions. Zones of bentonite clay occur in the upper and lower parts of the section, according to Vedder and others (1969). Rincon Shale is exposed in the northwestern portion of the quadrangle, where it, like the Vaqueros Sandstone, is deformed by and surrounds the Red Mountain Anticline. This formation is also parallel to and in contact with the Red Mountain Fault, which curves southward as it trends eastward across the northwestern quadrant.

The early to late Miocene marine Monterey Formation (also known as Modelo Formation) is conformable on the Rincon Shale and has two members exposed in the Ventura Quadrangle. The lower shale unit (Tml) consists of white-weathering, soft, fissile to punky clay shale, with interbeds of hard siliceous shale and thin limestone strata. The upper shale unit (Tm) consists of thin bedded, hard, platy to brittle, siliceous shale. On the south side of Red Mountain, these two units are juxtaposed along a strand of the Red Mountain Fault (Dibblee, 1988). On the east side of the Ventura River, these units dip steeply eastward and do not appear offset by the Red Mountain Fault, which turns abruptly northward in this area.

Late Miocene marine Sisquoc Shale (Tsq) is conformable on the Monterey Formation, and is exposed as overturned beds abutting the Red Mountain Fault. Sisquoc Shale consists of a light-gray silty shale or claystone, which is, locally, slightly siliceous and diatomaceous. Sisquoc Shale may also contain layers of tuffaceous sandstone (Vedder and others,1969).

The Pliocene to Pleistocene marine Pico Formation (Tp) has six members, is the most widespread geologic unit exposed in the Ventura Quadrangle, and is the unit with the most landslides. Near the western quadrangle boundary the oldest part of the Pico Formation, the “Repetto” Member (Tpr), is exposed near the Red Mountain Fault where it is mapped as discontinuous and questionable (Dibblee, 1988). The “Repetto” Member consists of gray claystone and contains microfauna of early Pliocene age. The younger, mostly gray, Pico (Tp) claystone member is conformable above the Repetto, and while similar, it is vaguely bedded and has a few thin strata of sandstone. Interbedded with the Pico claystone are two other members, the Pico sandstone-conglomerate (Tpsc) and the Pico sandstone (Tps). The sandstone/conglomerate member (Tpsc) may also have pebbles and cobbles of hard sandstone. The interbedded sandstone member (Tps) is a mostly light gray to tan sandstone, well bedded, in some places pebbly, and includes some interbedded claystone. The fifth member of the Pico Formation (QTpmc) consists of light gray sandstone and conglomerate with pebbles of hard sandstone and white siliceous shale. The sixth member of the Pico Formation (QTpm) is also known as the Mudpit Claystone member of the Santa Barbara Formation (Yerkes and others 1987; Yeats and Grigsby, 1987) and is reportedly of early Pleistocene to possibly late Pliocene age. This member is massive to vaguely bedded, gray claystone or mudstone, and may include the (QTpmc) member.

Early Pleistocene regressive marine Las Posas Sandstone (QTlp) is conformable on the Pico Formation and consists of weakly indurated tan to yellowish-brown fossiliferous sand, which includes pebbly sand strata with pebbles of siliceous shale and hard sandstone. This unit is exposed along the foothills in the southern portion of the quadrangle.

The early (?) Pleistocene, nonmarine to littoral marine Saugus Formation (QTs) is conformable on the Las Posas Sandstone, and consists of weakly consolidated alluvial deposits of gray to tan cobble-pebble gravel. Clasts are composed mostly of sandstone and some siliceous shale detritus in a light brown sandy matrix. This unit reportedly contains shell fragments at Grant Park and westward (Dibblee, 1988). This unit is exposed along the foothills in the southern portion of the Ventura Quadrangle.

Pleistocene to Holocene, dissected surficial units, unconformably overlie the Tertiary bedrock units in the Ventura Quadrangle. Older, cobble-boulder fan gravel and fanglomerate deposits (Qog) are largely composed of sandstone detritus, and the older alluvial deposits (Qoa) are remnants of weakly consolidated gravel, sand and silt. Younger deposits consist of alluvium (Qa) in stream and lowland environments, beach deposits (Qs), stream wash, and landslide deposits (Qls). Most artificial fill (af) within the Ventura Quadrangle occurs near or surrounding road or building projects.

Structural Geology

The Ventura Quadrangle is within the Western Transverse Ranges Province of southern California. The Transverse Ranges Province has a predominant east-west structural grain in contrast to the typical northwest grain of most of California. Geologically, this area includes one of the deepest sedimentary structures in the world. The channel region offshore forms the western part of the province, and is the partly submerged extension of the Ventura Basin, a structural depression that contains more than 50,000 feet of Cretaceous and Tertiary strata (Vedder and others, 1969).

Structurally, north-south compression of sedimentary strata, which began in Pleistocene time and continues to the present, caused crustal shortening and warping of the layers into the mostly east-west-trending series of anticlinal/synclinal folds present in the region (Keller, 1988). Crustal shortening also created the Red Mountain and Oakridge faults, between which the Santa Clara Trough, a downthrown graben, was formed (Nagle and Parker, 1971, *in* Keller, 1988; Yeats, 1983; Namson, 1987). The deformation, including rapid uplift in the recent past, has pushed up the sedimentary rocks and, concurrently, the Quaternary alluvial veneer to their current elevation. Estimates of the amount of compression and convergence range from 23 mm/yr (Yeats, 1983) to about 27 mm/yr (Namson, 1987). The intense and ongoing deformation that created the steep-limbed folds and faults also created a southward-arched curve of structural grain in the middle of the quadrangle. The rate of uplift in the flexural zone has apparently been balanced by the rate of downcutting of the Ventura River fluvial system in the area of the Red Mountain Fault, and has been estimated to range from 1.2 to 2.2 mm/yr (Rockwell, 1984).

In the Ventura Quadrangle, the major anticlinal/synclinal fold trends are the Red Mountain Anticline, Canada Larga Syncline, Ventura Anticline, and Ventura Syncline (Dibblee, 1988). Red Mountain Anticline is expressed as an eroded, doubly plunging anticlinal dome in the northwestern quadrant of the quadrangle, where it exposes uplifted and eroded Sespe Formation sedimentary rocks. This uplifted fold is surrounded by younger strata and cut by the Red Mountain Fault on the south limb.

The Canada Larga Syncline is the downwarp fold between the Red Mountain and Ventura anticlines. This fold has been attenuated near the surface at the Ventura River by the northward turn of the Red Mountain Fault. However, Putnam (1942) points out that the syncline axis probably continues beneath the fault, as indicated by the "contact between the upper and lower Pico, which crosses the Ventura River without significant offset south of the fault." Also according to Putnam, the Canada Larga Syncline can be mapped eastward from the Ventura River to Wheeler Canyon (7.5 miles) before disappearing under the alluvial sediments of the Santa Clara Valley.

The Ventura Anticline, within the middle part of the quadrangle, noses down on the west and east portions and is slightly domed in the middle. The Ventura Anticline, expressed by folded Quaternary Pico Formation sedimentary rocks across the middle portion of the Ventura Quadrangle, is also associated with major petroleum resources. The hilly middle and southern onshore areas are developed as oil fields (San Miguelito and Ventura Avenue Oil Fields). The axis of the Ventura Anticline is visible in Amphitheater Canyon along the Pacific Coast Highway, and in the oil fields above it and to the east. Here, the Ventura Anticline axis is exposed in Pico sandstone in a very steep and deeply dissected canyon. At the southern end of the hills in the Ventura Quadrangle, sedimentary layers on the south-facing limb of this anticline dip into the Ventura Syncline, present beneath the offshore and the onshore Quaternary sediments along the southern boundary of the quadrangle.

As the ongoing deformation continued, large north- and south-dipping reverse faults were formed that offset the bedrock formations. The largest exposed fault in Ventura Quadrangle is the Red Mountain Fault, a north-dipping reverse thrust fault with an apparent upward motion on the north side and downward motion on the south side of the fault. Displacement on this fault resulted in the geologic units being offset, with some units being pinched out along the fault. According to Putnam (1942), the "Vaqueros oyster reef nearly encircles the (Red Mountain) dome, except for a few places on the south side of the fold where it is eliminated by faulting." The eastern portion of the Red Mountain Fault turns northward at the Ventura River. The fault cannot be located within the sedimentary units of Sulphur Mountain to the north. The turn to the north by the Red Mountain Fault at the Ventura River may have weakened the structure at this location, allowing the river to incise the surrounding terraces and deposit its resultant floodplain.

Compression also affected sediments north and south of Red Mountain Fault, both within the Ventura Quadrangle and beyond. South of Red Mountain Fault, in the west-adjacent Pitas Point Quadrangle, movement on the Padre Juan Fault (which extends into Ventura Quadrangle) lifted the Pico Formation forming a graben in the middle. According to Nagle and Parker (1971) and Keller (1988) this graben widens with depth and to the east under the area of the Ventura Quadrangle.

Another thrust fault in the quadrangle, the Ventura Fault, is located along the southern base of the foothills where it is inferred in eroded steps in the alluvial fans, and has been located in trenches (Sarna-Wojiciki and others, 1976; Yerkes and others, 1987; Dibblee, 1988).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Ventura Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Landslides were mapped at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes compiled in a database. A version of this landslide inventory is included with Plate 2.1.

In general, landslides are abundant in Ventura Quadrangle where the sedimentary rocks have been deformed by several episodes of folding, faulting and uplift. Sedimentary units in Ventura Quadrangle range in hardness from unconsolidated to well indurated and associated slope angles vary from shallow to near vertical. The majority of landslides occur in the Pico Formation, which consists of a variety of strata, including vaguely bedded claystone, sandstone and conglomerate, with thin layers of sandstone and cobbles. Landslides and debris flows are also present in the more indurated Sespe Formation (Tsp) and on some slopes with adverse or dip-slope bedding. Landslides in the area range from minor surficial failures (soil and rock falls, debris slumps and/or flows), to large rotational, translational, and/or complex or mixed landslides, some of which are relatively old, deep and/or deeply eroded. Additionally, some terraces within the Ventura Quadrangle have physiography that can be mistaken for landslide morphology, and some areas have large slides in which the strata appear unaffected, but are in fact displaced.

Many of the landslides in the Ventura Quadrangle are well documented and considered active, as is the case of the landslide areas in the east Ventura Oil Field (Kerr and others, 1971). Data for the east Ventura Oil Field exists for several slides, dating back to the early 1920's. It has been inferred that, "all the slide areas in question have been moving intermittently for perhaps several hundred years" (Tide Water Associated Oil Company internal report, July 2, 1942, Courtesy of Aera LLC, 2002). The east Ventura Oil Field of the then Tide Water Associated Oil Company, experienced landslide movement in July of 1926, which destroyed several wells and other equipment in School Canyon. Tide Water reported that "the danger of placing facilities upon such slide areas, and more particularly, the drilling of wells within these areas, did not occur to the Company's operating personnel until severe and large earth movements took place on Slide Area No. 1, in July, 1926."

In March and April 1941, large landslides occurred in Slide Area No. 2 (also in School Canyon) of the east Ventura Oil Field, which was reportedly also coincident with an abnormal rainfall of over 40 inches the previous winter and spring. Some of the landslides in School Canyon moved again during the June 30, 1941, M = 5.9, Santa Barbara Earthquake. The same saturated formation in Slide Area No. 2 moved over 40 feet in early July, 1941, and again moved over 20 feet in November, 1941. Each time landslides in this portion of the east Ventura Oil Field moved they have rendered roads and oil wells and equipment inoperable, at least temporarily, if not permanently.

Reportedly, motion on the active slides over the years has usually been slow, punctuated by abrupt surges of slide masses down slope (notably in 1926, 1931, 1941, 1958, and 1969). According to the Tide Water memo, mentioned above, geologists were brought in to examine the situation for causes and fixes, and along with the engineers, it was, in their words, "the unqualified and joint opinion that the earth movements result from infiltration of water in the formation." Generally, recommendations were to dewater the formation, and grade and oil the surface to prevent future storm waters from entering the formation.

By 1970 landslides in the east Ventura oil field, then owned by Getty Oil Company, had destroyed 61 oil wells, and 53 were later repaired (Kerr and others, 1971). A portion of the largest landslides (Area No. 2) moved again in 2001, destroying 4 wells and 2 roads, which have subsequently been rebuilt (field reconnaissance and verbal communication, Aera LLC, 2002). In the Ventura Quadrangle rainfall for 2000 and 2001 was well below normal rainfall levels. Some geologic conditions prevalent in the east Ventura Oil Field also exist in the west Ventura Oil Field, as do the types of landslides. Some landslides, like the large Diablo Canyon Landslide, are older and have smaller newer landslides obscuring portions of the main slide body. Some landslides appear to have moved recently, even though rainfall totals have been low, whereas other slides have been obliterated by ongoing oil field activities (such as construction and placement of roads, well pads, and/or sumps) and some landslides have become overgrown with brush and, thereby, obscured.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Ventura Quadrangle geologic map were obtained from City of San Buenaventura Land Development and the County of Ventura Public Works Agency (see Appendix A). The locations of rock and soil samples taken for shear testing within the Ventura Quadrangle are shown on Plate 2.1. For the Ventura Quadrangle, shear test data from the adjoining Pitas Point Quadrangle were used to augment the data for several geologic formations in which little or no information was available.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups (Table 2.2) in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The Sespe and Saugus formations, which contain interbedded sandstone and shale, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material strength dominates where bedding dips into a slope (favorable bedding) while fine-grained material strength dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the Sespe and Saugus formations are included in Table 2.1.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

Within the Ventura Quadrangle, three shear strength test values for landslides were available. The results are summarized in Table 2.1.

VENTURA QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name	Number Tests Ventura/Pitas Point Quad	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	QTs(fbc)	2/0	34/34	35/35	340/200	Qs*, Qf, Qw,Qya2, Qyat1, Qyat2, Qoat1,QTlp, QTpmc, Tm, Tvq	35
GROUP 2	af, Qa** Qoa QTs(abc)	16/0 16/11 13/3 29/0	30/30 29/29 29/30 29/29	29/30	326/240	Qc, Qof, Qomt, Qoat2, Qym, QTpm, Tps, Tpr, Tm, Tsq, Tr, Tps(fbc)	30
GROUP 3	Qog, Tp	2/0 8/6	21/21 23/22	23/22	356/305	Tsp(abc)	22
GROUP 4	Qls	3/0	8/9				9

abc = adverse bedding condition, fine-grained material strength

fbc = favorable bedding condition, coarse-grained material strength
* = includes Qe, Qes
** = includes: Qya1, Qyf1, Qyf2

Formations for strength groups from Dibblee, 1988 and Quaternary members for strength groups from William Lettis and Associates (Hitchcock), 2000.

Table 2.1. Summary of the Shear Strength Statistics for the Ventura Quadrangle.

SHEAR STRENGTH GROUPS FOR THE VENTURA QUADRANGLE			
GROUP 1	GROUP 2	GROUP 3	GROUP 4
QTs(fbc), Qs, Qf, Qw,Qya2, Qyat1, Qyat2, Qoat1,QTlp, QTpmc, Tm, Tvq	af, Qa, Qoa, QTs(abc), Qc, Qof, Qomt, Qoat2, Qym, QTpm, Tps, Tpr, Tm, Tsq, Tr, Tps(fbc),	Qog, Tp, Tsp(abc)	Qls

Table 2.2. Summary of Shear Strength Groups for the Ventura Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Ventura Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8 to 7.1
Modal Distance:	3.8 to 7.5 km
PGA:	0.54 to 0.72 g

The strong-motion record selected for the slope stability analysis in the Ventura Quadrangle was the Corralitos record from the 1989 magnitude 6.9 (M_w) Loma Prieta earthquake (Shakal and others, 1989). This record had a source to recording site distance of 5.1 km and a peak ground acceleration (PGA) of 0.64g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding.

Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.086, 0.133 and 0.234 g, respectively. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Ventura Quadrangle.

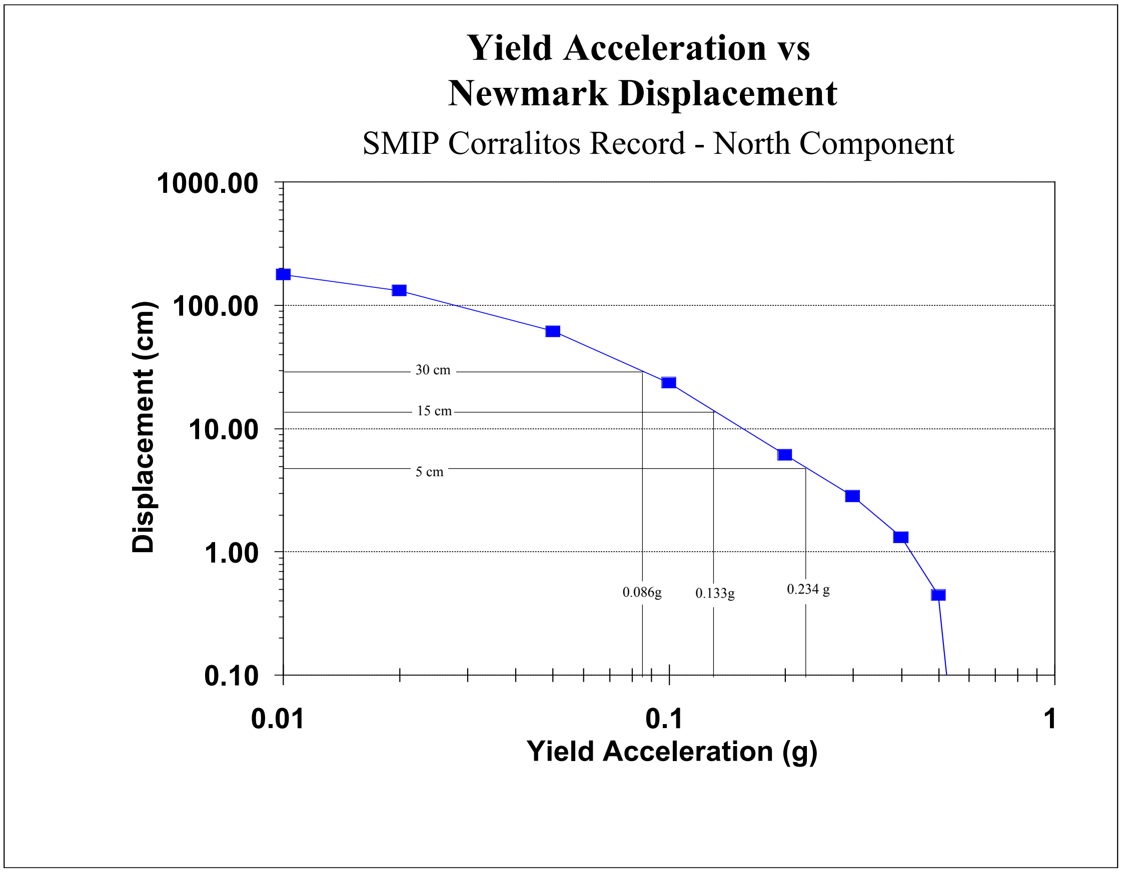

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Corralitos Record.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and **α** is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.086g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned
2. If the calculated yield acceleration fell between 0.133g and 0.086g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned
3. If the calculated yield acceleration fell between 0.234g and 0.133g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned
4. If the calculated yield acceleration was greater than 0.234g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

VENTURA QUADRANGLE HAZARD POTENTIAL MATRIX				
Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (% Slope)			
	Very Low	Low	Moderate	High
1 (35)	0 to 44%	45 to 55%	56 to 60%	> 60%
2 (30)	0 to 33%	34 to 43%	44 to 48%	> 48%
3 (22)	0 to 17%	18 to 26%	27 to 32%	> 32%
4 (9)	0	0 to 2%	3 to 8%	> 8%

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Ventura Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, **all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.**

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 4 is included for all slope gradient categories.

2. Geologic Strength Group 3 is included for all slopes steeper than 17 percent.

3. Geologic Strength Group 2 is included for all slopes steeper than 33 percent.

4. Geologic Strength Group 1 is included for all slopes steeper than 43 percent.

This results in approximately sixty-three (63) percent (the equivalent of 27 square miles) of the land portion of the Ventura Quadrangle lying within earthquake-induced landslide zones of required investigation.

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REFERENCES

Bailey, T.M., 1947, Origin and migration of oil into Sespe Redbeds, California: Bulletin of the American Association of Petroleum Geologists, v. 31, no. 11, part II, p.1913-1935.

Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257C, 1 sheet, scale 1:62,500.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 12 p.

Dibblee, T.W., Jr., 1988(a), Geologic Map of the Ventura and Pitas Point Quadrangles, Ventura County, California, Map #DF-21, Scale 1:24,000, Dibblee Geological Foundation.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.

Intermap Corporation, 2002, Global Terrain product handbook and quick start guide: http://www.globalterrain.com/pdf%20files/GT_product_handbook_v2_3.pdf

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, No. 4, p. 406-421.

Keller, M.A., 1988, Geologic basis for the assessment of undiscovered oil and gas resources of the Ventura Basin Province, California, 1987 Assessment: U.S. Geological Survey Open-File Report 87-450 M, 30 p.

Kerr, P.F., Stroud, R.A.,and Drew, I.A., 1971, Clay mobility in landslides, Ventura, California: American Association of Petroleum Geologists Bulletin, v. 55, no.2, p.267-291.

McCrink, T.P., 2001, Mapping earthquake-induced landslide hazards in Santa Cruz County *in* Ferriz, H. and Anderson, R., *editors*, Engineering geology practice in northern California: California Geological Survey Bulletin 210 / Association of Engineering Geologists Special Publication 12, p.77-94.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.

Nagle, H.E. and Parker, E.S., 1971, Future oil and gas potential of onshore Ventura Basin, *in* Cram, I.H., *editor*, Future petroleum provinces of the United States—their geology and potential: American Association of Petroleum Geologists Memoir 15, v.1, p. 254-297.

Namson, J.S., 1987, Structural transect through the Ventura Basin and western Transverse Ranges *in* Davis, T.L. and Namson, J.S., *editors*, 1987, Structural evolution of the western Transverse Ranges: Pacific Section S.E.P.M., v. 48A, p. 29-41.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, No. 2, p. 139-160.

Putnam, W.C., 1942, Geomorphology of the Ventura region, California: Geological Society of America Bulletin, v. 53, no.5, p.691-754.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao. T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open File Report 96-08; U.S. Geological Survey Open File Report 96-706, 33 p.

Rockwell, T.K., Keller, E.A., Clark, M.N. and Johnson, D.L., 1984, Chronology and rates of faulting of Ventura River terraces, California: Geological Society of America Bulletin, v. 95, p. 1466-1474.

Sarna-Wojcicki, A.M., Williams, K.M. and Yerkes, R.F., 1976, Geology of the Ventura Fault, Ventura County, California: U. S. Geological Survey Miscellaneous Field Studies Map MF- 781, scale 1:6,000, 3 sheets.

Sarna-Wojcicki, A.M., Lajoie, K.R., Robinson, S.W. and Yerkes, R.F., 1979, Recurrent Holocene displacement on the Javon Canyon Fault—rates of faulting and regional uplift, western Transverse Ranges, California: abstract *in* Geological Society of America, Annual Meeting, Cordilleran Section, Program with Abstracts, v. 11-3, p.125.

Shakal, A., Huang, M., Reichle, M., Ventura, C., Cao, T., Sherburne, R., Savage, M., Darragh, R. and Peterson, C., 1989, CSMIP strong-motion records from the Santa Cruz Mountains (Loma Prieta), California earthquake of 17 October 1989: California Department of Conservation, Division of Mines and Geology, Office of Strong Motion Studies Report OSMS 89-06, 196 p.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Earthquake Center, 2002, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating landslide hazards in California: T.F. Blake, R.A. Hollingsworth, and J.P. Stewart, *editors*, Southern California Earthquake Center, University of Southern California, 108 p.

Vedder, J.G., Wagner, H.C. and Schoellhamer, J.E., 1969, Geologic framework of the Santa Barbara Channel region *in* Geology, petroleum development, and seismicity of the Santa Barbara Channel Region, California: U.S. Geological Survey Professional Paper 679A, p.1-12.

Wang, Y., Mercer, J.B., Tao, V.C., Sharma, J., and Crawford, S., 2001, Automatic generation of bald earth digital elevation models from digital surface models created using airborne IFSAR: http://www.intermaptechnologies.com/PDF_files/asprs2001_Intermap_E.pdf

Watts, W.L., 1896, Oil and gas yielding formations of Los Angeles, Ventura and Santa Barbara counties: California State Mining Bureau Bulletin 11, Parts II and III, p.22-60.

Weber, F.H., Jr., Cleveland, G.B., Kahle, J.E., Kiessling, E.F., Miller, R.V., Mills, M.F. and Morton, D.M., 1973, Geology and mineral resources study of southern Ventura County, California: California Division of Mines and Geology Preliminary Report 14, 102 p., Plate 3, map scale 1:48,000 (compiled).

William Lettis and Associates, 2000, Digital Quaternary geologic map of the Ventura 7.5-minute Quadrangle: digitized at scale 1:24000.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Yeats, R.F., 1983, Large-scale Quaternary detachments in Ventura basin, southern California: Journal of Geophysical Research, v. 88, no. B1, p. 569-583.

Yeats, R.F. and Grigsby, F.B., 1987, Ventura Avenue anticline: Amphitheater locality, California, pp. 219-223, *in* Hill, M.L., *editor*, Geological Society of America Centennial Field Guide Volume I, p. 219-223.

Yeats, R.F., Huftile, G.J. and Grigsby, F.B., 1988, Oak Ridge Fault, Ventura Fold Belt, and the Sisar Decollement, Ventura Basin, California: *in* Sylvester, A.G. and Brown, G.C., *editors*, Coast Geological Society Guidebook 64 Ventura California, p.133-144.

Yerkes, R.F., Sarna-Wojiciki, A.M. and Lajoie, K.R., 1987, Geology and Quaternary deformation of the Ventura area, Ventura County *in* Recent reverse faulting in the Transverse Ranges, California: U. S. Geological Survey Professional Paper 1339, p.169-178

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p 7-6-2 to 7-6-26.

AIR PHOTOS

Fairchild, 1928, Flight C297, D-6 to D-12. Vertical scale 1:24,000.

Pacific Western Aerial Surveys, 1988, Flight PW-VEN, 6-107 to 6-109, 6-140 to 6-144 (2/15/89), 6-172 to 6-176 (11/16/88), and 6-210 to 6-215 (11-22-88). Vertical scale 1: 23,000.

U. S. Department of Agriculture (USDA), 1953, Flight AXI, 4K-41 to 4K-48, 4K-71 to 4K-78, 4K87 to 4K-94, 4K-105 to 4K-112, (1/5/53), and 5K-19 to 5K-22 (7/12/53). Vertical scale 1:20,000.

U. S. Geological Survey (USGS) 1967, Flight GS-VBUK, 1-82 to 1-85 (8/12/67), 1-119 to 1-122, and 1-131 to 1-134 (8/13/67). Vertical scale 1:17,000.

U. S. Geological Survey, 1998, Flight USGS AREA A, 3A-3 to 3A-8, and 4A-2 to 4A-5 (07-08-98). Vertical scale 1:24,000.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA*

SOURCE	NUMBER OF TESTS SELECTED
Ventura Quadrangle	
City of Buenaventura, Land Development	**62**
County of Ventura, Public Works Agency	**24**
Pitas Point Quadrangle	**31**
Total Number of Shear Tests	**117**

* Due to the limited rock strength shear test data available for the Ventura Quadrangle, data from the adjacent Pitas Point Quadrangle was combined to expand the data sets for both quadrangles. See, “Seismic Hazard Zone Report 073” for listing of data source for the Pitas Point Quadrangle.

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Ventura 7.5-Minute Quadrangle, Ventura County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997. The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://gmw.consrv.ca.gov/CGS/index.htm

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

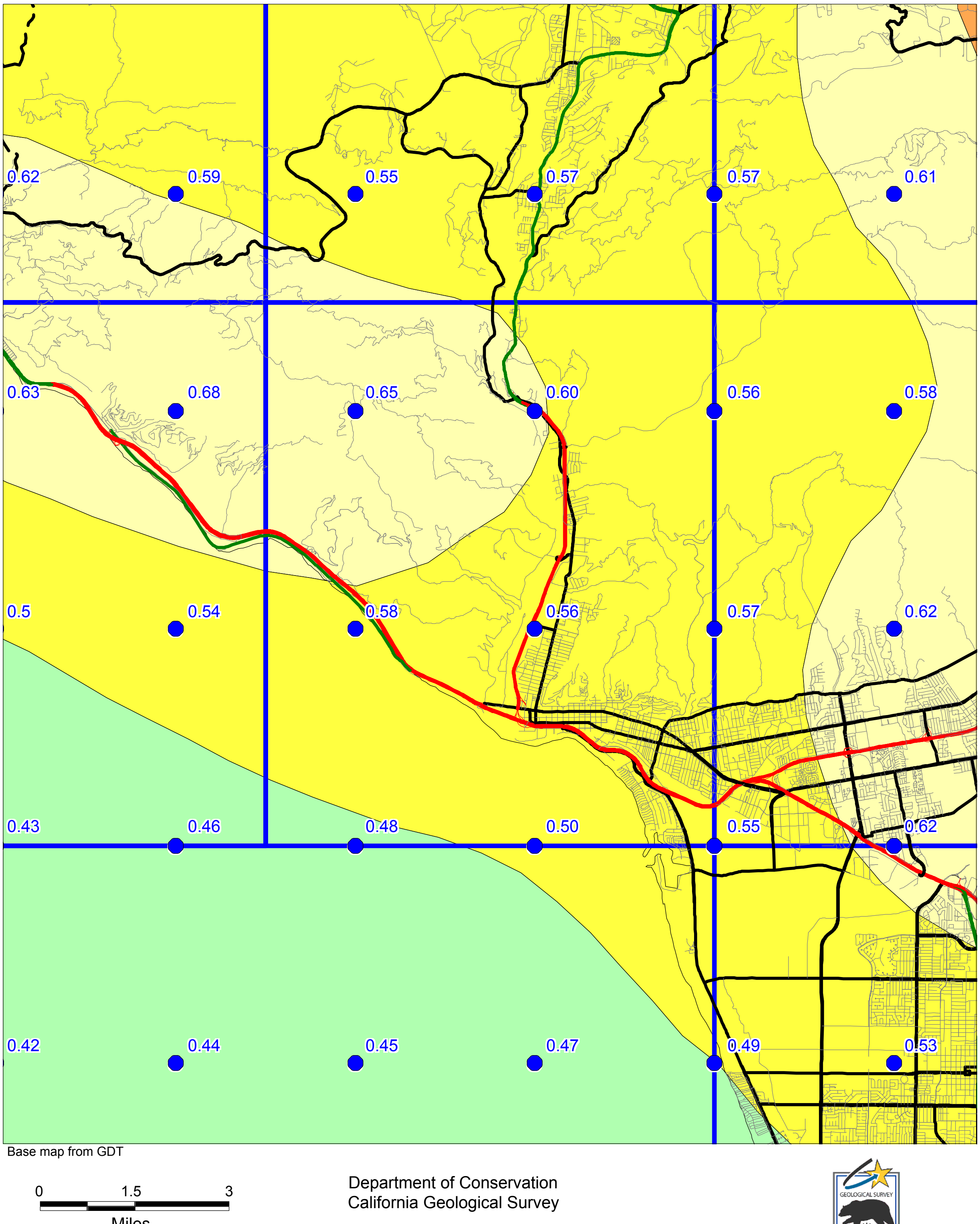
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

VENTURA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



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California Geological Survey

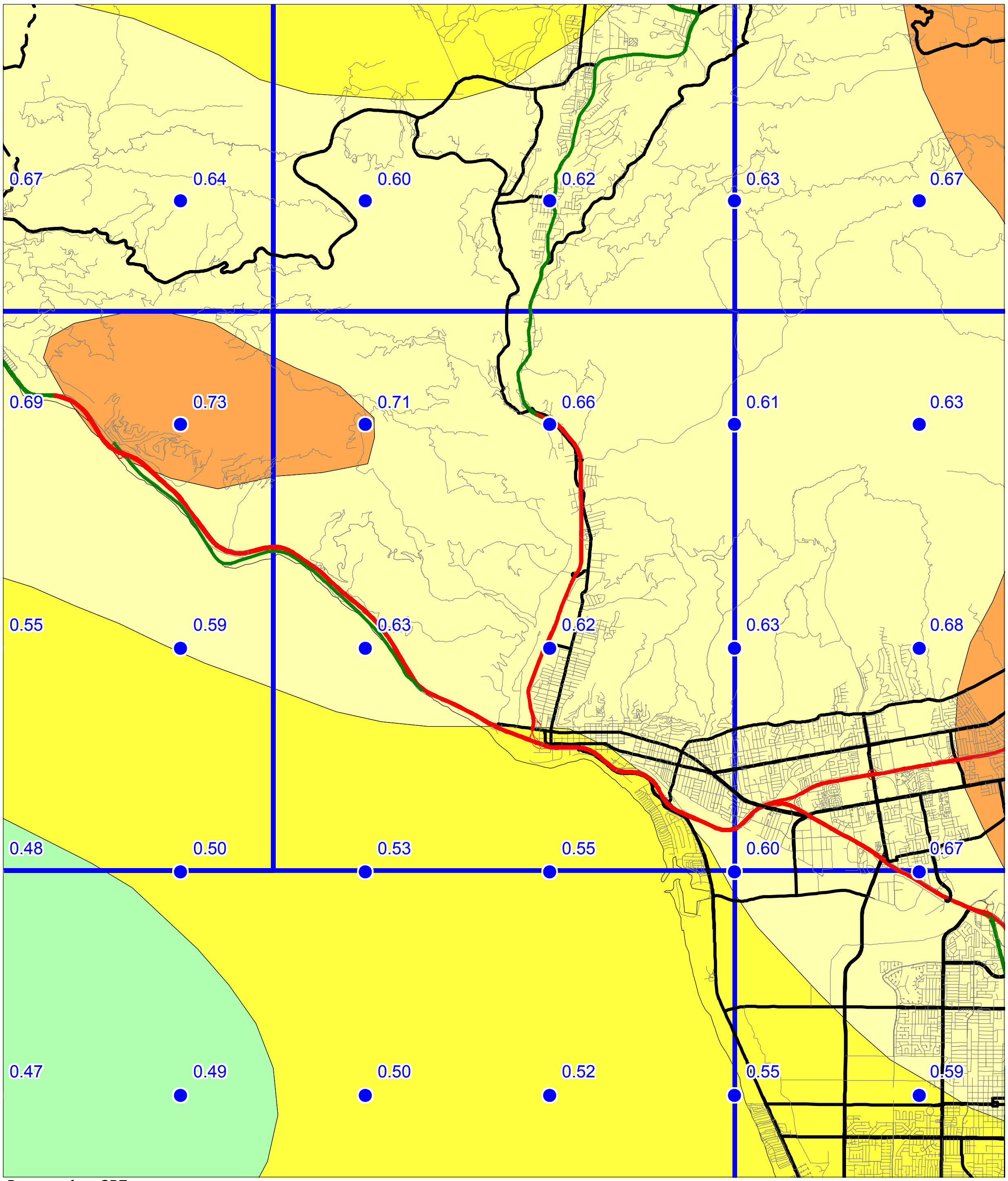
Figure 3.1

VENTURA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

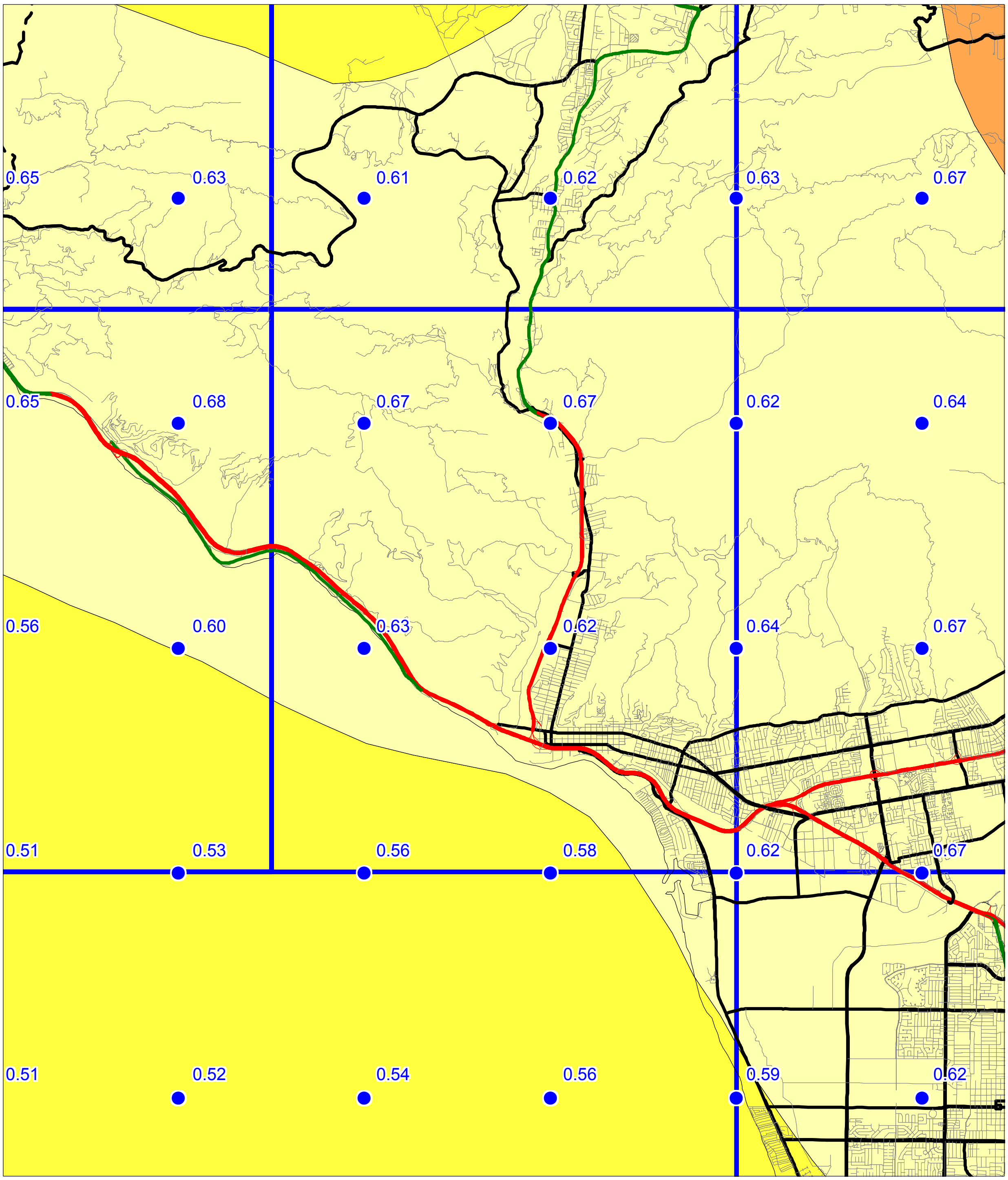
Figure 3.2

VENTURA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

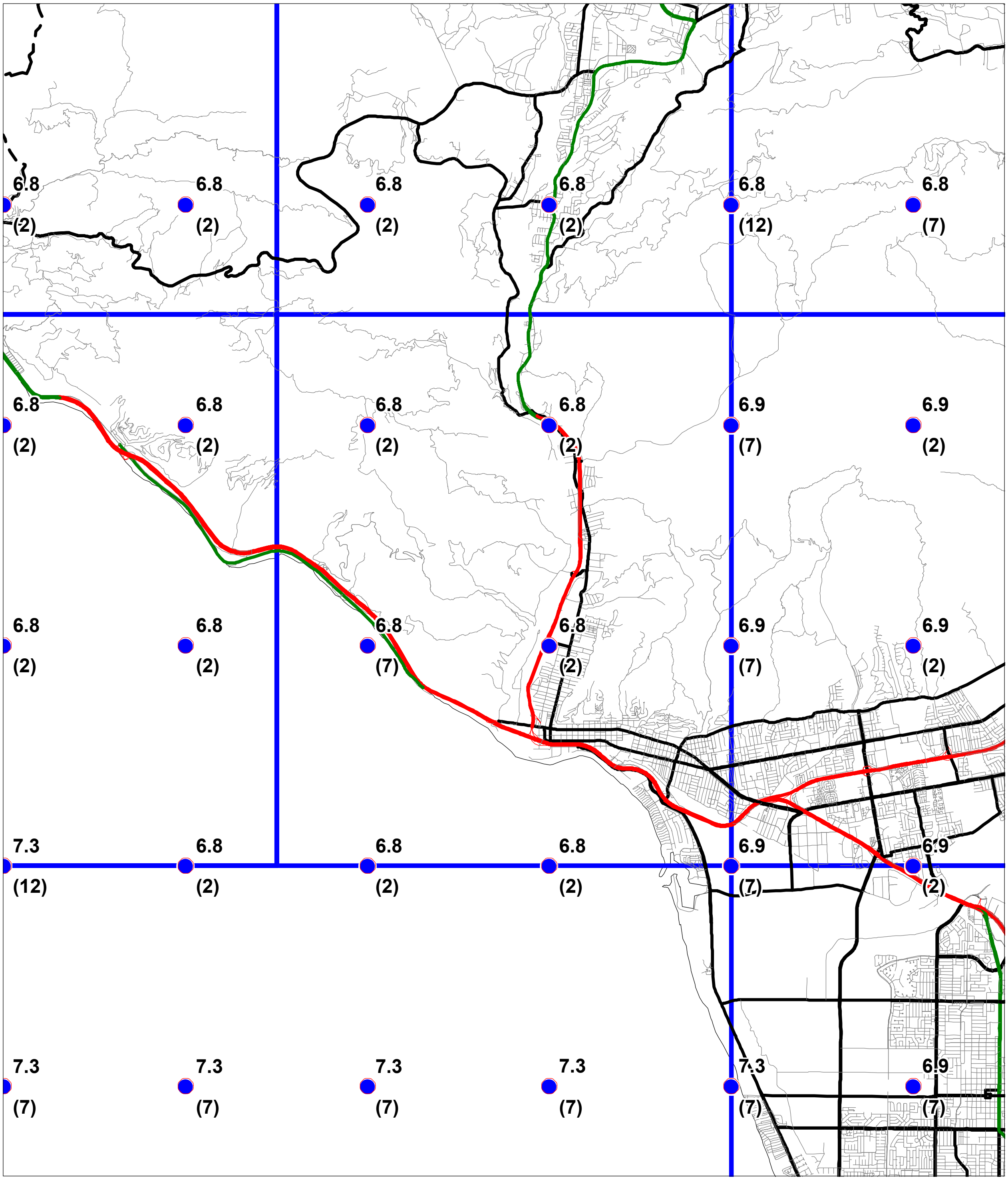
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

VENTURA 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map from GDT

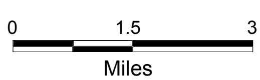


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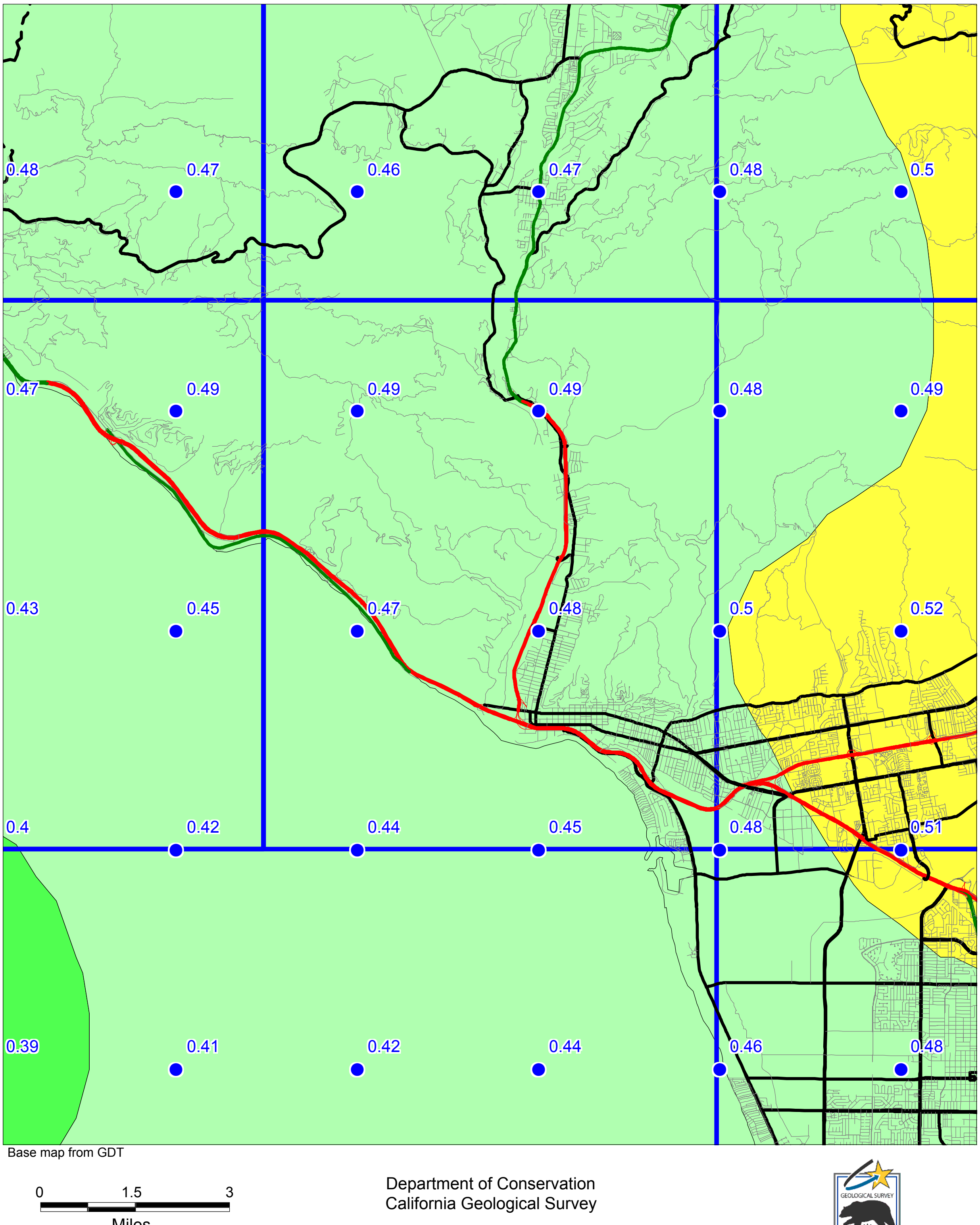
Figure 3.4

VENTURA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

2001

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures

3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

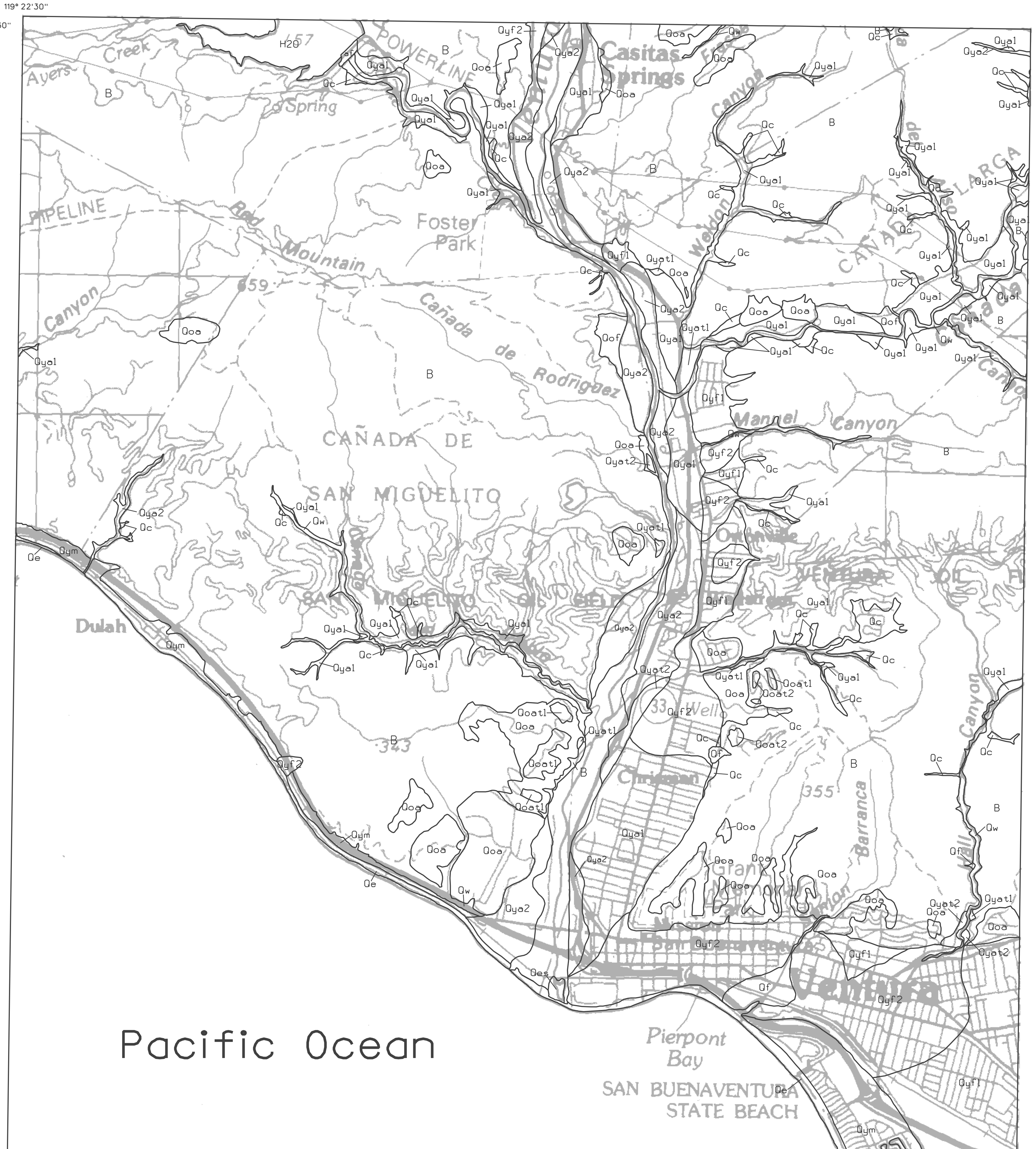
Real, C.R., Petersen, M.D., McCrink, T.P. and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, EERI, Oakland, CA.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.



Base map enlarged from U.S.G.S. 30 x 60–minute series

VENTURA QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

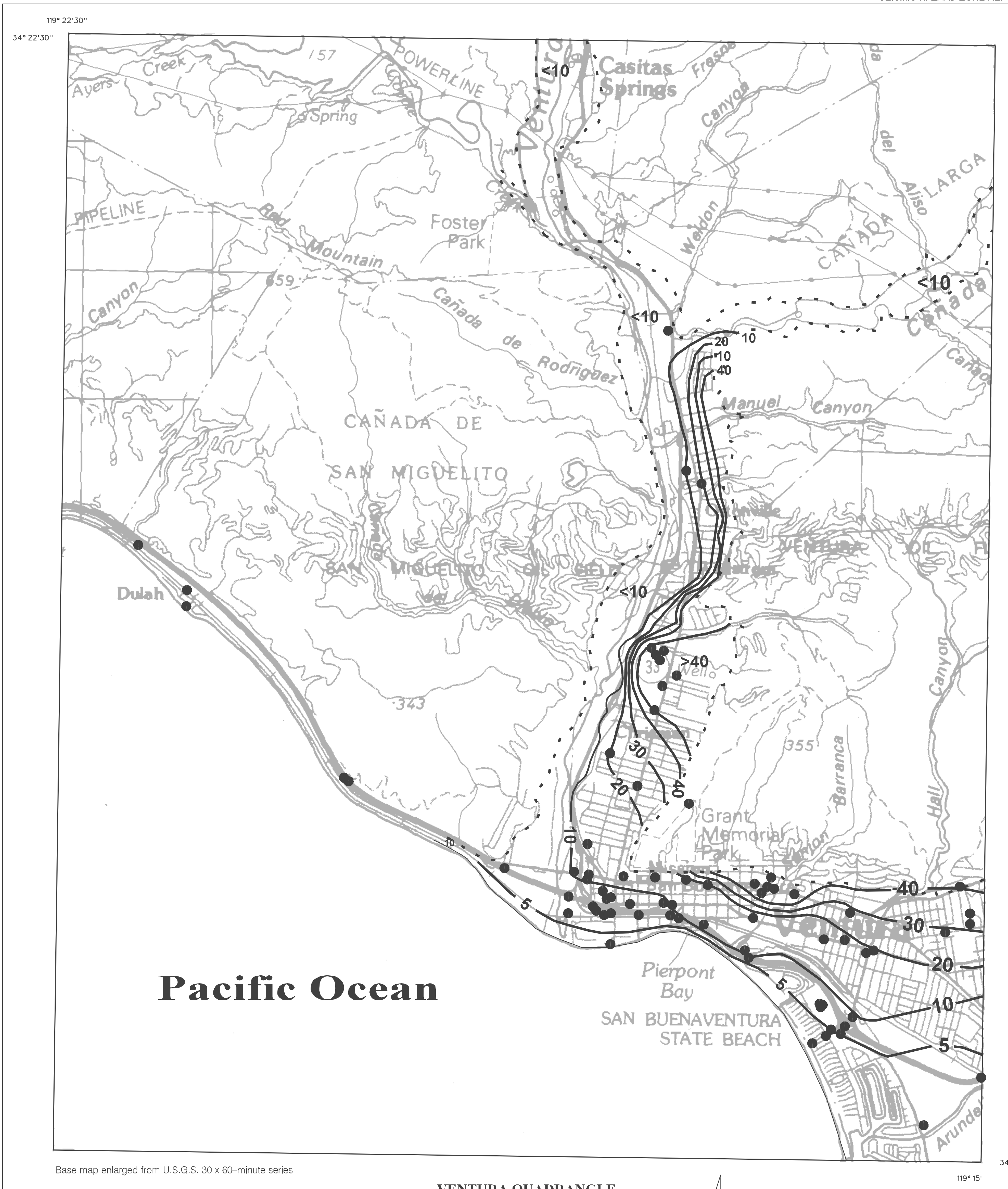
N

B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary geologic map of the Ventura 7.5-minute Quadrangle (William Lettis & Associates, 2000).

CALIFORNIA GEOLOGICAL SURVEY
JAMES F. DAVIS, STATE GEOLOGIST

STATE OF CALIFORNIA-GRAY DAVIS, GOVERNOR
THE RESOURCES AGENCY-MARY D. NICHOLS, SECRETARY
DEPARTMENT OF CONSERVATION-DARRYL W. YOUNG, DIRECTOR



Base map enlarged from U.S.G.S. 30 x 60–minute series

VENTURA QUADRANGLE

SCALE

1 .5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology"
in Section 1 of report for descriptions of units.

Alluviated Valley Boundary

Geotechnical borings used in liquefaction evaluation

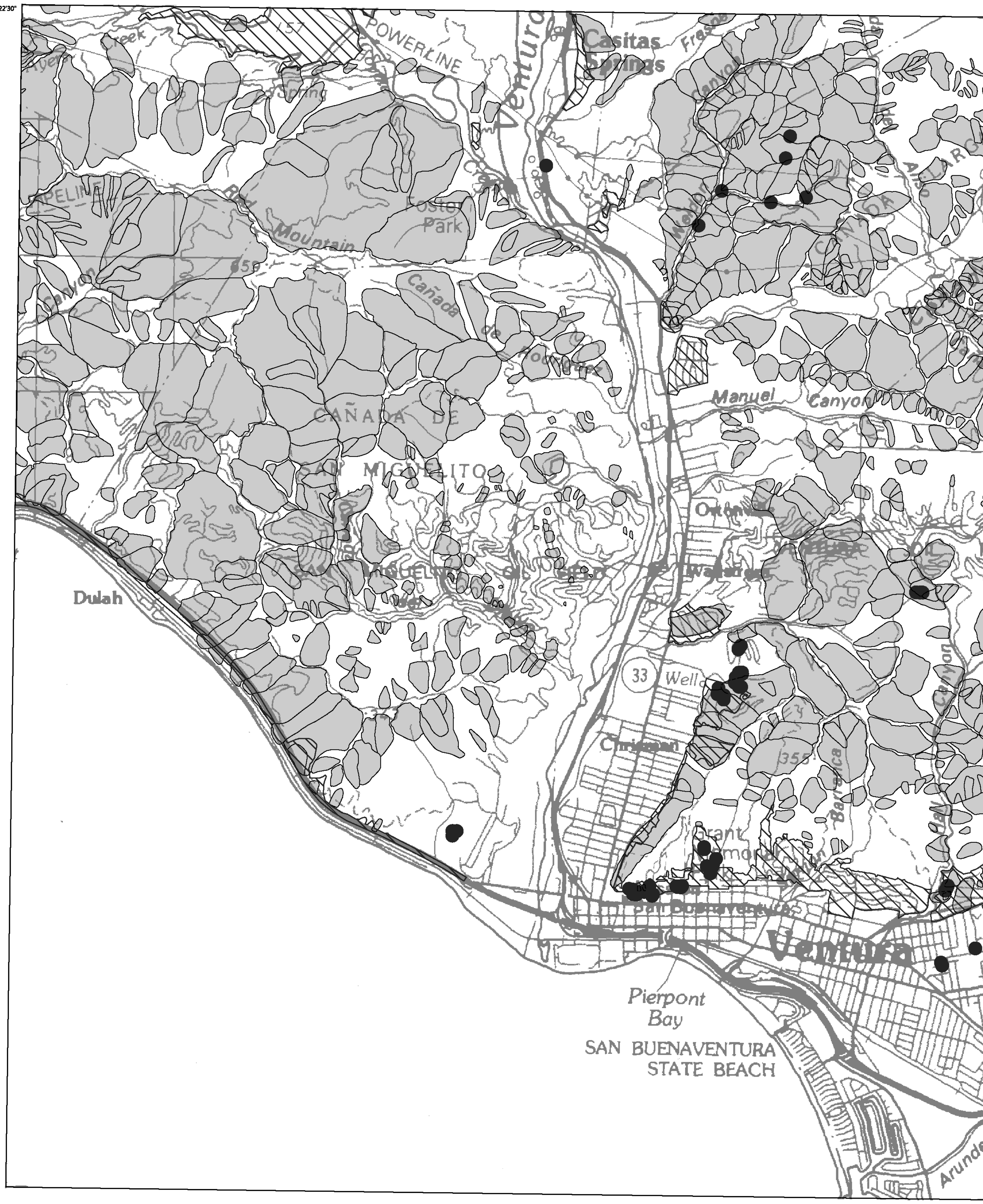
20 — Historically shallowest ground-water depth contours (in feet)

>40 Historically shallowest ground-water depth greater than 40 feet over a broad area

<10 Historically shallowest ground-water depth less than 10 feet over a broad area

Plate 1.2 Historically shallowest ground–water depths and borehole locations in alluviated valley areas of the Ventura 7.5–minute Quadrangle, California.

119°22'30
34°22'30"



34°15'
119°15'

Base map enlarged from U.S.G.S. 30 x 60-minute series

VENTURA QUADRANGLE

SCALE

1 .5 0 1 MILE
1000 0 2000 4000 6000 FEET
1 .5 0 1 KILOMETER

N

● Shear test sample location
Landslide
Area of significant grading

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Ventura 7.5-minute Quadrangle, California